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Biological Treatment Technology for Recycling Agricultural Waste for Sustainable Agriculture and Environmental Protection

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Abstract

Due to the increase in the intensive agricultural production system and operation, the practice of recycling agriculture waste in the sustainable agriculture and for the protection of environmental quality has changed. Because of this change, a review of the existing agricultural waste characteristics, the role of biological treatment technology, and the potential integration of treatment technology is made. Among the biological treatment technologies reviewed, only the composting process, biogas production and aerobic treatment of wastewater for sustainable agricultural production, and environmental quality are reviewed. Also, the integration of both anaerobic and aerobic treatment processes to achieve waste recycling and an example of the achievement of treatment technology and economics are both presented. Although other potential recycle alternatives, such as algae production, fish production, aquatic weeds and land application are not included in this review, they can be easily integrated into the three biological treatment technologies reviewed for the achievement of sustainable agriculture and environment quality protection for the intensive agricultural production system. Modification and integration are the two promising components of the biological treatment technology for the achievement of the goals planned.

Key words

Agricultural waste characteristics, biological treatment technology,

aerobic/anaerobic treatment, integration of anaerobic and aerobic, sustainable agriculture, environmental protection, biogas production, composting process, treated wastewater reuse, economic evaluation.

Introduction

Agricultural production is becoming more intensive with larger operations. The increased efficiency may generate various types of environmental problems, such as excessive nutrients and short oxygen levels in both the receiving soil and water body. General or common indicators, such as fish killing, odor generation, contamination of ground water and the decrease of crop production, occur because of improper management of agricultural waste/wastewater. These potential problems in environmental quality are closely associated with the wastes/residues from the agricultural production system. These wastes/residues can be in the form of animal wastes from animal production facilities, runoff and leachate from fertilized and manured fields, and liquid/solid wastes from food producing operations. Thus, the recycling agricultural wastes/wastewater has to consider and evaluate the consequence of the negative impacts of environmental quality. Generally, there are four possible methods for agricultural waste recycling, and are listed as follows (Polprasert, 1996; Loehr, 1984).

- Agricultural reuse
- Biogas production
- Aquacultural reuse
- Reuse of wastewater

The recycling method for agricultural wastes is mainly determined by the characteristics of various types of agricultural waste/wastewater. For example, animal waste/wastewater naturally pertains a high organic concentration and a low volume of flow, while food processing wastewater has high volume of flow and a lower organic concentration.

Characteristics of Agricultural Wastes

Although agricultural wastes have a very broad variety including food processing wastes, animal wastes, agricultural chemicals losses, crop residues etc., the potential agricultural wastes recycling in this review only focuses on the animal and food processing wastes. The characteristics of these wastes are important and should be understood. This will permit the type of treatment, recycling, and disposal to be properly selected. These wastes can be in the form of liquid or solid. Feasible treatment, recycling, and disposal methods will be varied with these characteristics as shown in Table 1. As indicated, the

biological treatment technology or method is suitably applied for both dissolved suspended and solid organic wastes. The parameter to be measured for the organic content includes BOD_5 (5 days Biochemical Oxygen Demand), COD (Chemical Oxygen Demand) and TVS (Total Volatile Solid) contents. The magnitude of these contents is COD > TVS > BOD_5. This reflects how much of the organic content remains in the agricultural wastes and can be further recycled for energy, animal feed and nutrient production via biological treatment methods. Examples for the characteristics of animal waste and food processing waste (tapioca starch waste) are presented in Tables 2 and 3, respectively. With the knowledge of the waste characteristics, it provides an opportunity for the reuse/recycle of bioenergy, animal feed, and soil conditioner production through the application of the biological treatment technology.

Role of Biological Treatment Technology for Agricultural Wastes Recycling

Understanding the biological treatment fundamentals is very important. Without understanding these fundamentals, the treatment processing will appear as a "black boxes". The objective of recycling agricultural wastes for maintaining sustainable agriculture and environmental protection will be hindered. In general, aerobic and / or anaerobic processes are the two primary biological treatment technologies which have been practiced. Aerobic process involves the reaction of the oxidation of organic matter in the wastes. In contrast, the anaerobic process is functioned by an anaerobic microorganism without the presence of oxygen. Thus, the main reaction products for the aerobic process are CO_2, H_2O and microbial biomass, while for the anaerobic process, the products are CH_4, CO_2, H_2O and microbial biomass. It must be emphasized that the cell yield (biomass produced per organics consumed) is lower in the anaerobic process, which has more advantages in sludge handling. These processes can be applied with various objectives of recycling, disposal and reuse. Common biological treatment processes are presented in Table 4. These biological treatment processes are mainly for dissolved and suspended organic wastewater. Applications of these technologies depend on the specific objective of agricultural waste recycling for sustainable agriculture and environmental quality protection. For recycling agricultural wastes, it is very important that production of composting product, biogas production and aerobic treatment for wastewater reuse should be reviewed and evaluated.

♦ For Composting Process:

It is an aerobic – biological treatment process, where the organic residues

or agricultural wastes are converted into humus by the numerous soil microbial biomass. As indicated by Polyprasert (1996), the objectives for applying composting process include waste stabilization, pathogen inactivation, nutrient and land reclamation, and waste product drying. The biochemical reactions can be divided into different stages of microbial growth with the change of temperature as shown in Figure 1. The composting process can be done in open windrows or enclosed with air supplying in a controlled unit shown in Figures 2 and 3, respectively. Composting can be completed in 5 – 7 days for the enclosed - air supplying controlled unit, whereas in open windrows, it may require for 3 – 8 days. In order to maintain proper microbial reactions in the composting process, the C/N ratio should be maintained about 20:1 to 30:1. For animal waste with some crop residues, they may provide an ideal C/N ratio to achieve an optimal stabilization process and conserve most of the nutrients. Benefits of recycling composted agricultural wastes to the soil include improved overall soil fertility and modify the soil pH. Also, if it is a long term application of composting product to the soil, soil erosion can be reduced, water retention capacity raised, soil structure improved, and subsequently, the crop production is improved.

◆ For Biogas Production Process:

In addition to composting technology, biogas production or anaerobic treatment technology is growing more popular and receiving more attention to animal producers. According to Christensen and Payseur (National Summit, 2003), approximately 250 million dry tons of animal manure is produced yearly in the United States. The National Pollution Discharge Elimination System (NPDES) and the Effluent Limitation Guidelines have been modified to include provision for confined animal feedlot operation (CAFOs), establishing technology - based effluent discharge standard for feedlot (beef, dairy, swine, and poultry subcategories). Also, regulation modifications are considered necessary because many agricultural sites are already saturated with nutrients (N and P), making it increasingly more necessary to reduce solid volume and to transport the manure off – site for use or disposal. According to Christensen and Payseur (National Submit, 2003), innovative technology and approaches are needed to make advances on the most different environment challenges in animal agriculture in the U.S. One technology that has demonstrated potential to assist in mitigating the impacts of animal manure on air and water resources, while producing other benefits such as energy and soil (fertilizer/conditioner), has been anaerobic digestion or anaerobic treatment, or biogas production. This technology has the potential to fit seamlessly for the agricultural production system, and to provide both economic and environmental benefits. Anaerobic

process is the natural process to stabilize the organic without the presence of oxygen. As reported by Polypraset (1996), the product of this process under normal operation conditions is presented as follows:

Methane (CH_4)	55 – 60%
Carbon dioxide (CO_2)	35 – 45%
Nitrogen (N_2)	0 – 3%
Hydrogen (H_2)	0 – 1%
Hydrogen sulfide (H_2S)	0 – 1%

Methane contains high calorific value ($\cong$ 9,000 kcal/m^3). The approximate heat value of the biogas is 4,500 – 6,300 kcal/m^3 depending on the content of CH_4. The anaerobic treatment process not only produces energy, it also provides waste stabilization (reduces the oxygen demand material or organic content), nutrient reclamation, pathogen inactivation and reduction of attraction of rodents and flies. Although there are some disadvantages, such as complicated operation and maintenance, and the market of biogas and digested sludge, which are still remained. The development of more advanced technology for the design and operation of anaerobic bioreactor may overcome these disadvantages. In general, two different types of anaerobic organisms, mesophilic and thermophilic, are functioned for the anaerobic treatment process as shown in Figure 4. It is necessary to maintain and operate under these two different temperatures which are considered optimal or suitable for the anaerobic treatment process. In addition to temperature, other operational factors, such as hydraulic and biomass retention times, nutrient requirement, inhibition prevention and mixing, all need to be maintained properly, as shown in Table 5. For the past decade, there are many anaerobic bioreactors being designed and operated as shown in Figure 5. Various types of bioreactors need to be designed and operated depending on the type of agricultural waste applied, temperature environment, reuse/recycle of the digested waste/wastewater, and biogas utilization.

♦ Aerobic Treatment for Wastewater Reuse:

This biological treatment process, generally, is integrated by following the anaerobic treatment unit process for further removal of oxygen demand materials. This will achieve more effectively for sustainable agriculture and environmental protection. Conventional activated sludge process as shown in Figure 6, can be applied to polish the anaerobic treated effluent for reuse in the agricultural production system. Although these processes can remove oxygen demand material very effectively, further removal of nitrogen and phosphorous are required to be integrated in order to improve the soil properties and increase crop production. Therefore, there are two types of biological treatment processes which allow the removal of nutrients and organic matter (oxygen demand

materials) at the same time because these processes include anoxic or anaerobic conditions in the aerobic treatment systems. These two processes are SBR (Sequential Batch Reactor) and continuous feed intermittently decanted (CEID) as shown in Table 6. Also, several activated sludge processes are modified to include anaerobic or anoxic zones in the systems for the removal of nitrogen and phosphorus as shown in Figure 7. Currently, Yang and his associates developed an EMMC (Entrapped Mixed Microbial Cell) Process as shown in Figure 8, for the combined removal of carbon and nitrogen simultaneously (Yang et al., 2002, 2003, 2004). This technology may hold a great potential for reuse/recycle of biologically treated wastewater because of its simple operation/maintenance for simultaneous removal of carbon and nitrogen contained in the wastewater. Pilot plant study using EMMC technology for both domestic sewage and agricultural wastewater is currently being initiated and developed. Also, a pilot plant study (Yang et al, 1997) using suspended culture on the combined anaerobic and aerobic treatment and reuse system was investigated for pig wastewater as shown in Figure 9. The result is presented in Table 7. This indicates that the integration of the biological treatment process (anaerobic and aerobic processes) is required to recycle and reuse of agricultural wastewater in order to maintain sustainable agriculture and protect environmental quality. Economic evaluation was conducted for this system. Two on-farm field studies for the swine waste treatment/reuse system including solid/liquid separation, anaerobic treatment and aerobic (complete and intermittent) treatment and polishing (or sedimentation) units have been investigated. About 20 – 25 sows operation was used to evaluate the overall process performance and economic evaluation. Based on the optimal operation process performance for these two systems, economic evaluation was conducted using the NPW (Net Present Worth) method. This value is related to the capital and annual operational and maintenance costs, with the annual interest rate of 6%, a life expectancy of 10 years. The land used for this evaluation was owned by the procedures. Farm size of 300, 1000, 2000, 3000 and 5000 size were evaluated for the NPW. It was assumed that the sludge and gas produced from the system could be reused and had value. Based on the break-even point analysis, the break-even point for integrating the complete aeration system is 830 pigs (average weight of 77 kg), and 166 heads for integrating intermittent aeration system as shown in Figures 10 and 11, respectively. It was also found that the utilization of biogas and digested sludge is essential for the benefit or profit of operating the integrating treatment system. Apparently, integrating the intermittent aeration unit in the swine waste treatment system provides reduction of energy consumption cost and reuse/disposal of treated wastewater without causing deterioration of environmental quality. It is, therefore, that the recycling of agriculture waste for

sustainable agriculture and environmental quality protection requires the inclusion of biological treatment technology.

Although the listed review on the biological treatment technologies are not totally included for the utilization of agricultural residues and protection of environmental quality, they are indeed the main streams of biological treatment technologies for the intensive agricultural production system. They can be modified to meet the goal or need, residue availability, the capability of operating individuals, and market and economic of products. As quoted by Loehr (1984), "The pressures for better resource conservation and pollution control are increasing, the need for better residue utilization exists, and many applicable technologies are available. The challenge is to change personal and public philosophies toward residue utilization and to provide the appropriate incentives to stimulate greater use of utilization technologies."

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Table 1. Feasible Treatment and Disposal Methods with Wastes of Different Characteristics

Wastes	Treatment and disposal methods
Liquid	
Dissolved organic wastes	Biological treatment, land treatment
Dissolved inorganic matter	Land disposal, physical or chemical treatment
Suspended organic wastes	Sedimentation, biological treatment, chemical precipitation, land treatment
Suspended inorganic matter	Sedimentation, land treatment, chemical treatment
Solid	
Organic wastes	Incineration, composting, land treatment, dehydration, animal feed
Inorganic wastes	Land disposal

Table 2. Bioengineering parameters of animal wasters (Taiganides, 1978)

Parameter	Symbol	Units	Pork pigs	Laying hens	Feedlot beef	Feedlot sheep	Dairy cattle
Wet waste	TWW	% TLW/day	5.1	6.6	4.6	3.6	9.4
Total solids	TS	% TWW	13.5	25.3	17.2	29.7	9.3
		% TLW/day	0.69	1.68	0.70	1.07	0.89
Volatile solids	TVS	% TS	82.4	72.8	82.8	84.7	80.3
		% TLW/day	0.57	1.22	0.65	0.91	0.72
Biochemical oxygen demand	BOD_5	% TS	31.8	21.4	16.2	8.8	20.4
		% TVS	38.6	29.4	19.6	10.4	25.4
		% TLW/day	0.22	0.36	0.13	0.09	0.18
COD/BOD_5 ratio	COD/BOD_5	Ratio	3.3	4.3	5.7	12.8	7.2
Total nitrogen	N	% TS	5.6	5.9	7.8	4.0	4.0
		% TLW/day	0.039	0.099	0.055	0.043	0.036
Phosphate	P_2O_5	% TS	2.5	4.6	1.2	1.4	1.1
		% TLW/day	0.017	0.077	0.008	0.015	0.010
Potash	K_2O	% TS	1.4	2.1	1.8	2.9	1.7
		% TLW/day	0.010	0.035	0.013	0.031	0.015

Table 3. Units mass emission rate (UMER) values of tapioca starch wasterwater in g/kg root (Thanh, 1984)

	Wastewater				
Characteristics	**A**	**B**	**C**	**D**	**Combined**
First-grade factory					
COD	**0.69**	**55.2**	**6**	**--**	**61.9**
BOD_5	**0.33**	**26.5**	**2.9**	**--**	**29.8**
Suspended solids	**0.54**	**10.5**	**3.7**	**--**	**15.7**
Dissolved solids	**4.91**	**46.3**	**9.6**	**--**	**60.8**
Second-grade factory					
BOD_5	**1.8**	**44.8**	**2.1**	**2.2**	**48.7**
Total solids	**3.1**	**102.8**	**2.2**	**2.2**	**109.2**
Suspended solids	**3.1**	**83.5**	**0.6**	**0.6**	**87.2**

Table 4. Common Biological Treatment Processes (Loehr, 1984)

Aerobic	Anaerobic
Activated sludge units	Anaerobic lagoons
Trickling filters	Digesters
Oxidation ponds	Anaerobic filters
Aerated lagoons	Photosynthetic
Oxidation ditch	Oxidation ponds
Suspended growth	Adherent growth (fixed film)
Activated sludge	Trickling filters
Aerated lagoons	Rotating biological contractors
Mixed digesters	Anaerobic filters
Oxidation ditch	Denitrification columns

Table 5. Process control parameters for anaerobic processes (Yang & Wang, 1990)

Parameter	Requirement	References
pH	6-8 (6.6-7.6 for methanogens)	Obayashi & Gorgan, 1985
Alkalinity	2500-5000 mg $CaCO_3$/L	Obayashi & Gorgan, 1985
pH_2	10-8 to 10-5 M	McCarty & Smith, 1986
Nutrient	C:N:P = 100:6:1	Jannet & Dennis, 1975
Trace nutrients	Fe, Co, Ni, & Sulfide	Speece, 1983
Toxicity	Toxicants: heavy metals, cyanide, ammonia, formaldehyde, pharmaceuticals, detergents, disinfectants, & solvents.	Speece, 1983
Temperature	30-40°C (50-70°C for thermophilic processes)	Henze & Harremos, 1983

Table 6. Comparison of SBR & CFID (Yang & Wang, 1990)

	SBR	CFID
No. of Tank	1	1
Feeding	**Batch**	**Continuous**
Operation Periods:		
Feeding	+	
React (Aeration)	+	+
Settle.	+	+
Decant	+	+
Idle	+	**Optional**

Table 7. Settled Effluent Quality of Combined Anaerobic Process (Two Stages without Sludge Recycling) and Aerobic System (Yang, 2001)

Parameter	Average value
Effluent Setting Time (minutes)	**4**
HRT for Anaerobic Process (days)	**32**
HRT for Algal-Biomass Receway System (days)	**3**
TCOD (mg/L)	**411**
$TBOD_5$ (mg/L)	**58**
SS (mg/L)	**50**
TKN (mg/L)	**64**
NH_3-N (mg/L)	**39**
NO_3-N (mg/L)	**20**
Total P (mg/L)	**33**
pH	**7.18**

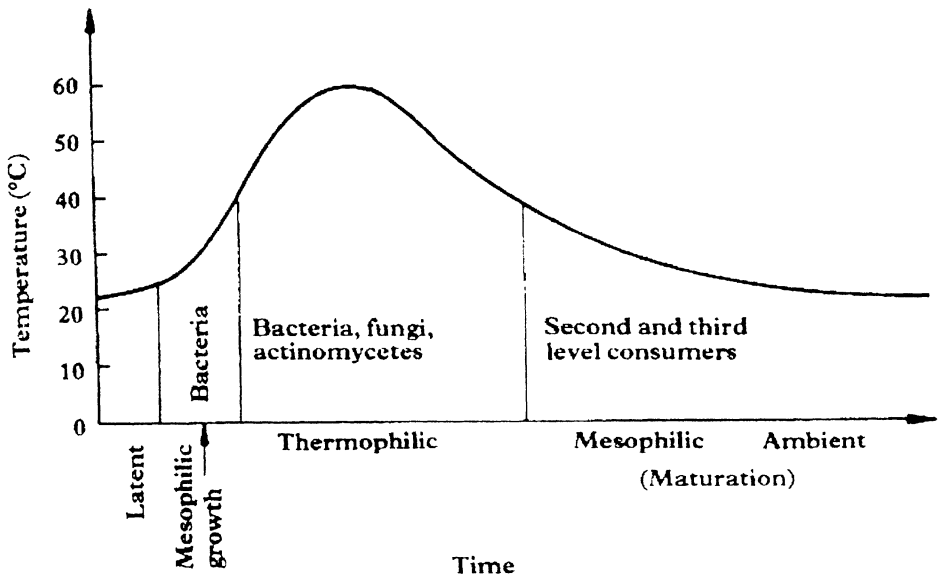

Figure 1. Patterns of temperature and microbial growth in compost piles (Polprasert, 1996)

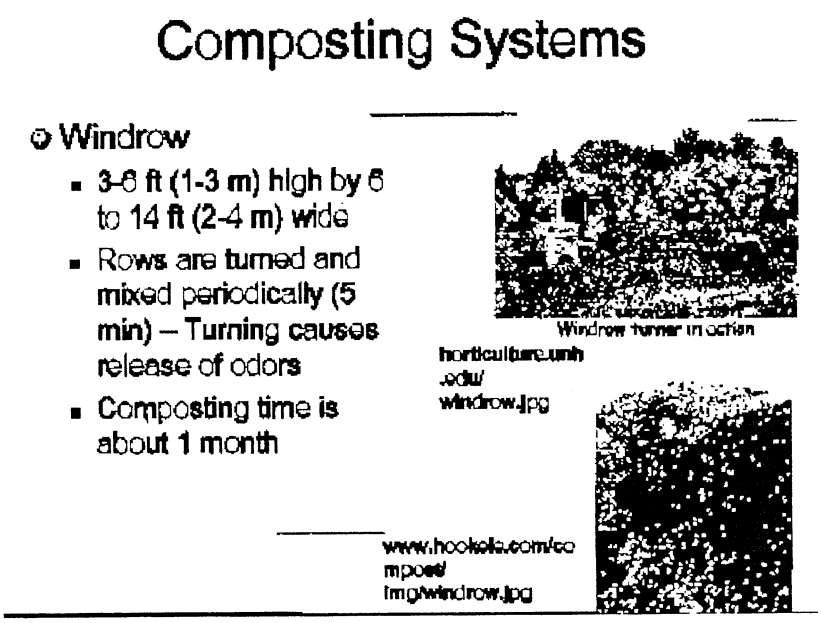
Composting Systems
Windrow
3-6 ft (1-3 m) high by 6 to 14 ft (2-4 m) wide
Rows are turned and mixed periodically (5 min) – Turning causes release of odors
Composting time is about 1 month
Windrow turner in action
horticulture.umh.edu/windrow.jpg
www.hookola.com/compost/img/windrow.jpg

Figure 2. Window Composting System (Adams, 2001)

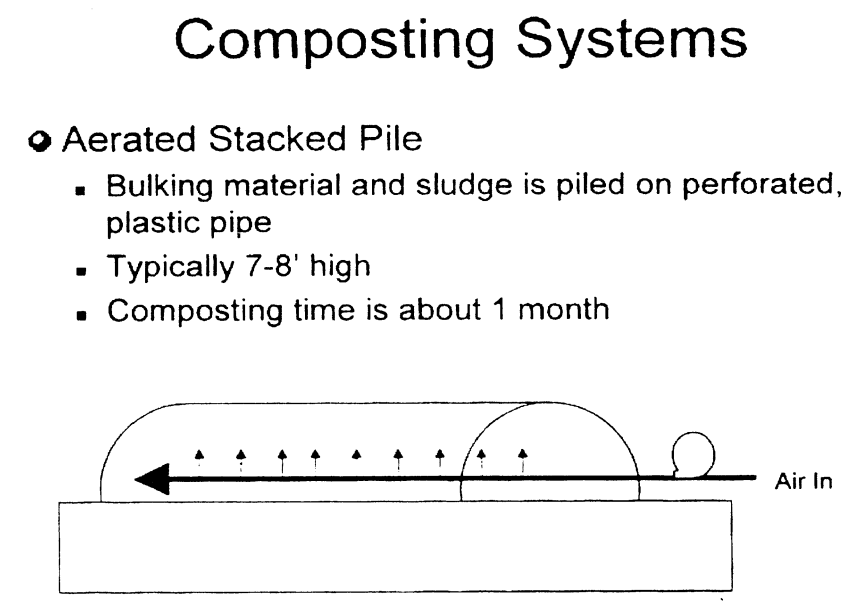
Composting Systems
Aerated Stacked Pile
Bulking material and sludge is piled on perforated, plastic pipe
Typically 7-8' high
Composting time is about 1 month
Air In

Figure 3. Aerated Composting Systems (Adams, 2001)

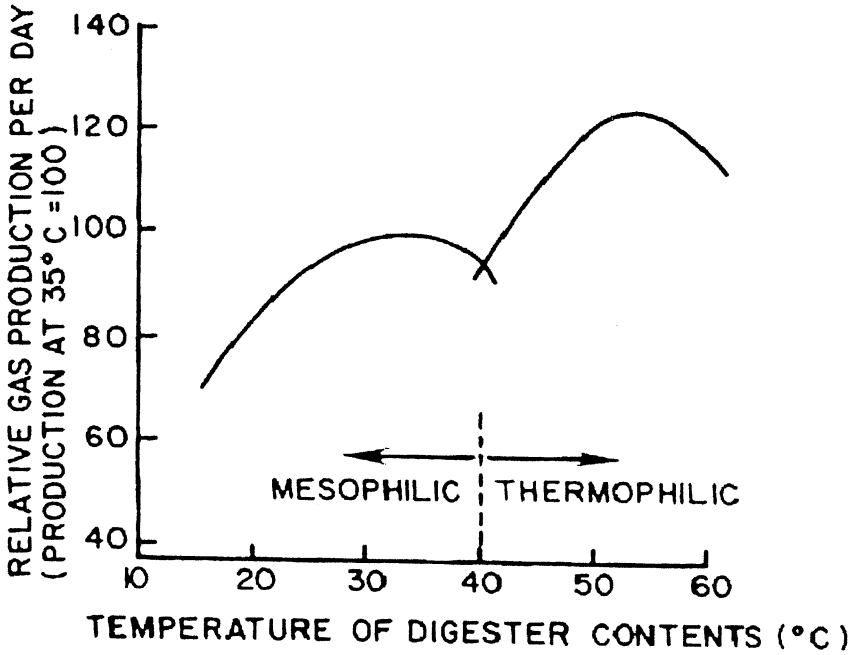

Figure 4. Temperature will affect activity of the microorganisms in anaerobic processes (Loehr, 1984)

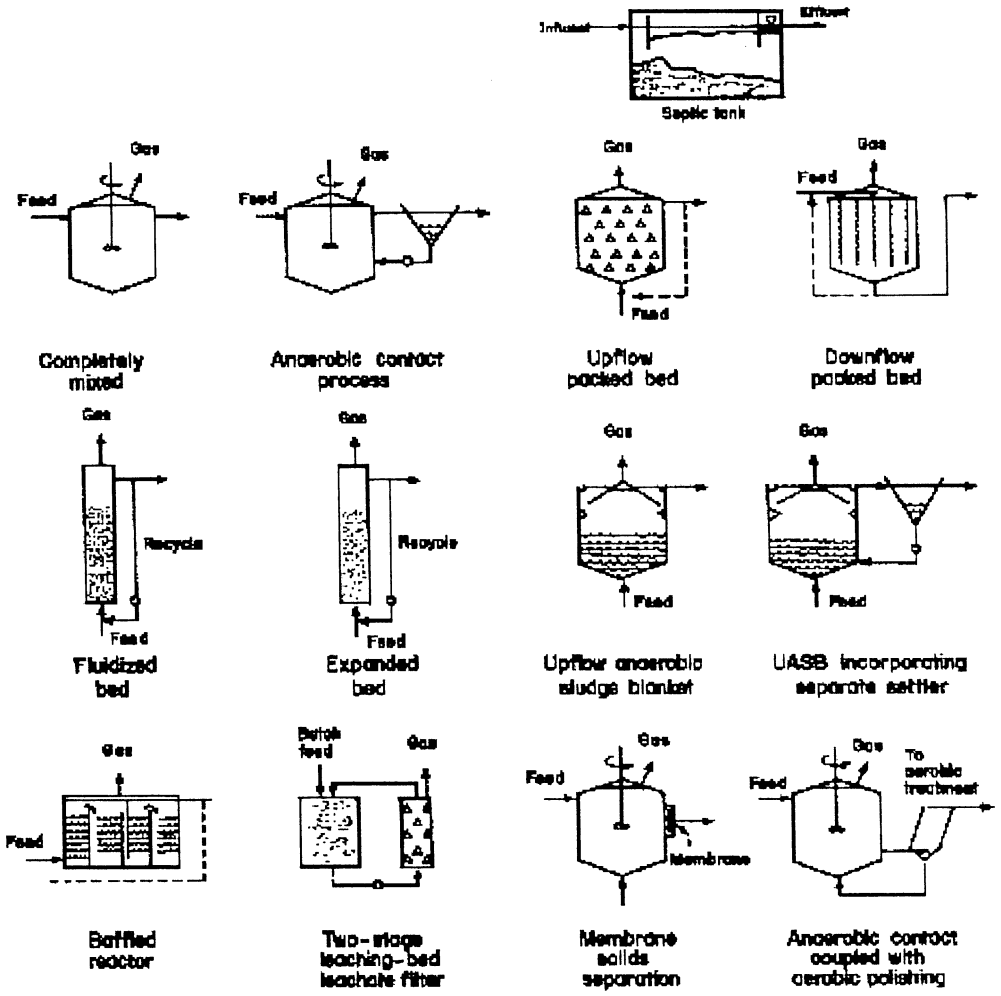

Figure 5. Reactor configurations for anaerobic biotechnology (Jewell, 1987 and Speece, 1983)

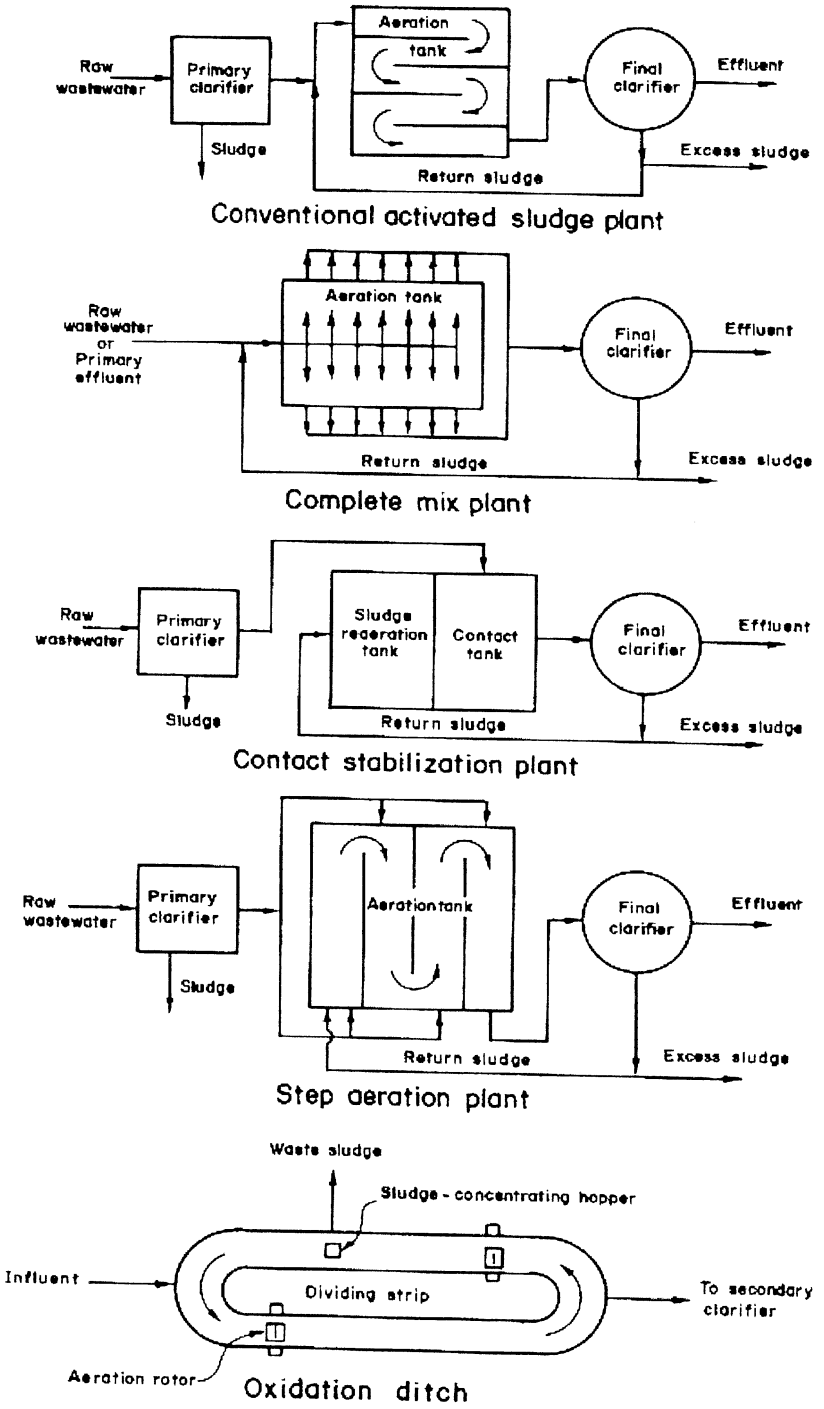

Figure 6. Modifications of activated sludge process (Cheremisinoff, 1987)

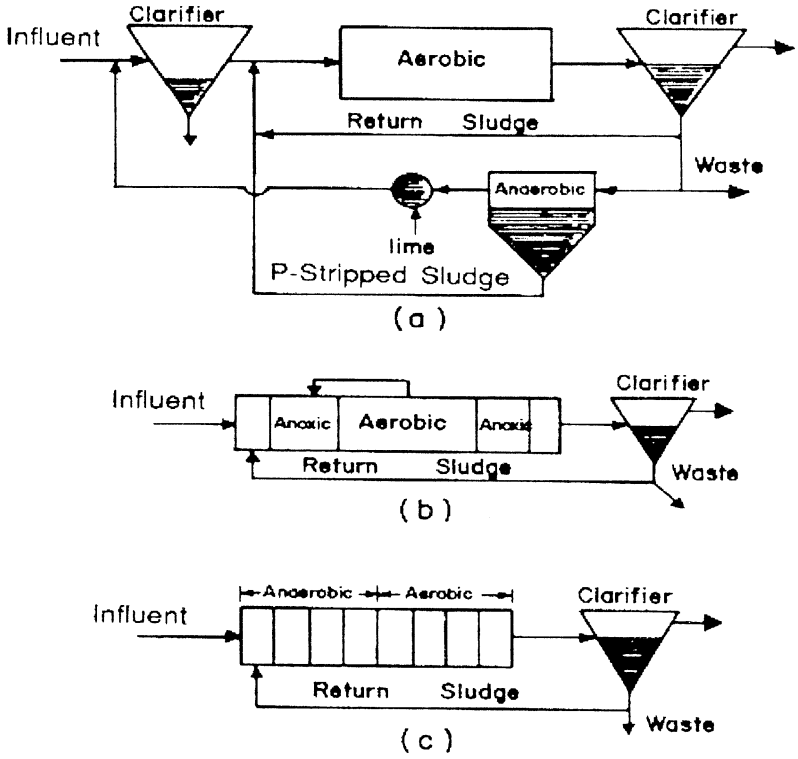

Figure 7. Various biological phosphate removal processes: (a) Phostrip process; (b) Badenpho process; (c) Air product process (Hao & Chang, 1988)

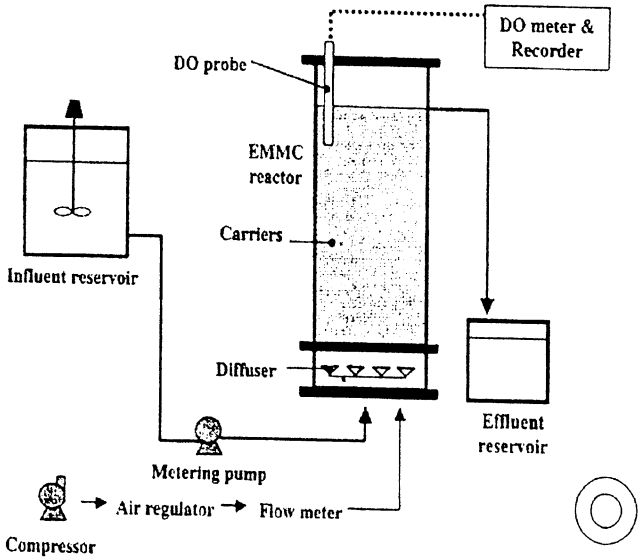

Figure 8. Schematic diagram of EMMC process (Yang, 2001)

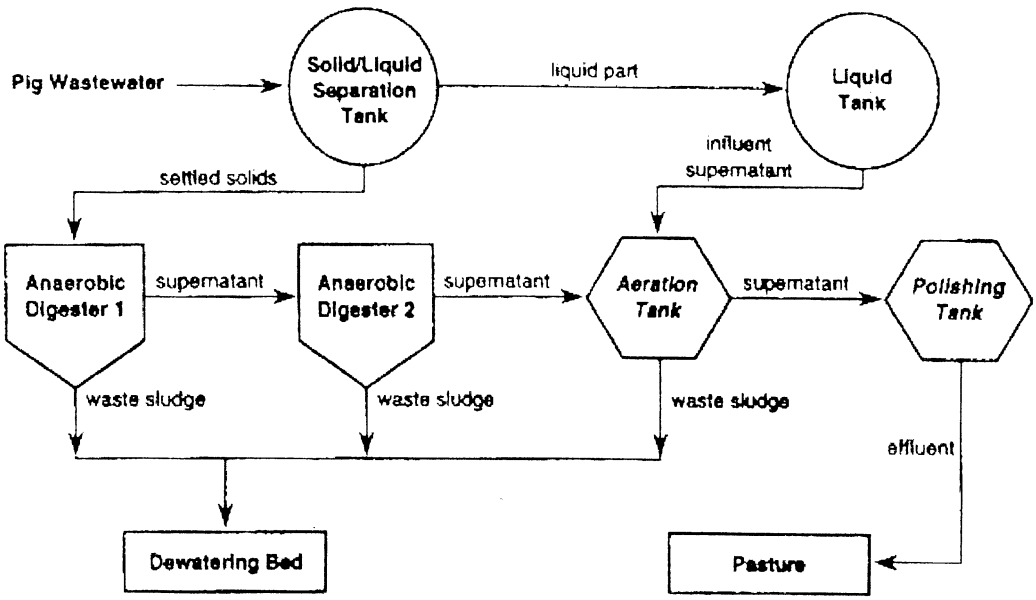

Figure 9. Schematic showing components of swine waste treatment system (Yang et al. 1997)

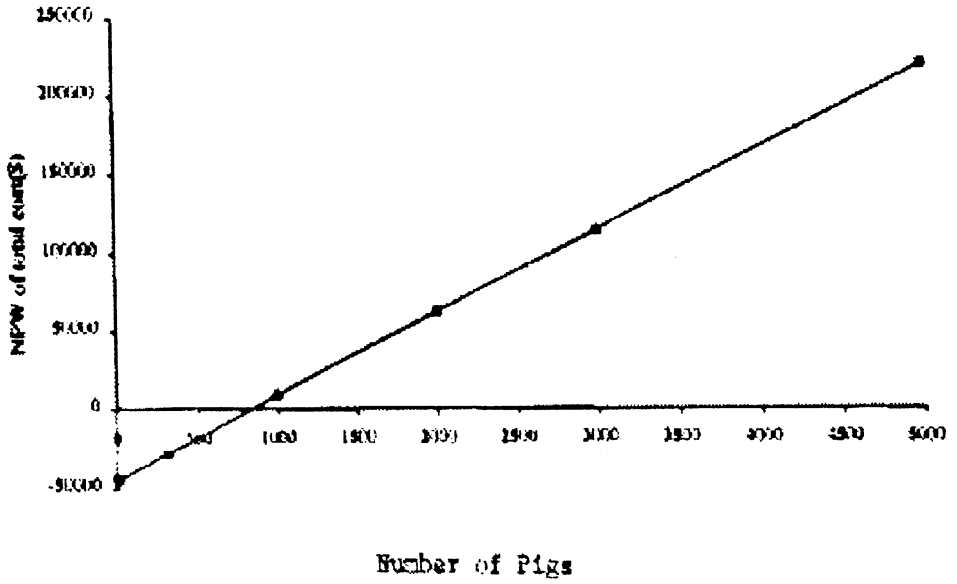

Figure 10. Relationship between pig numbers and present worth (NPW) of total cost. (Yang, 2001)

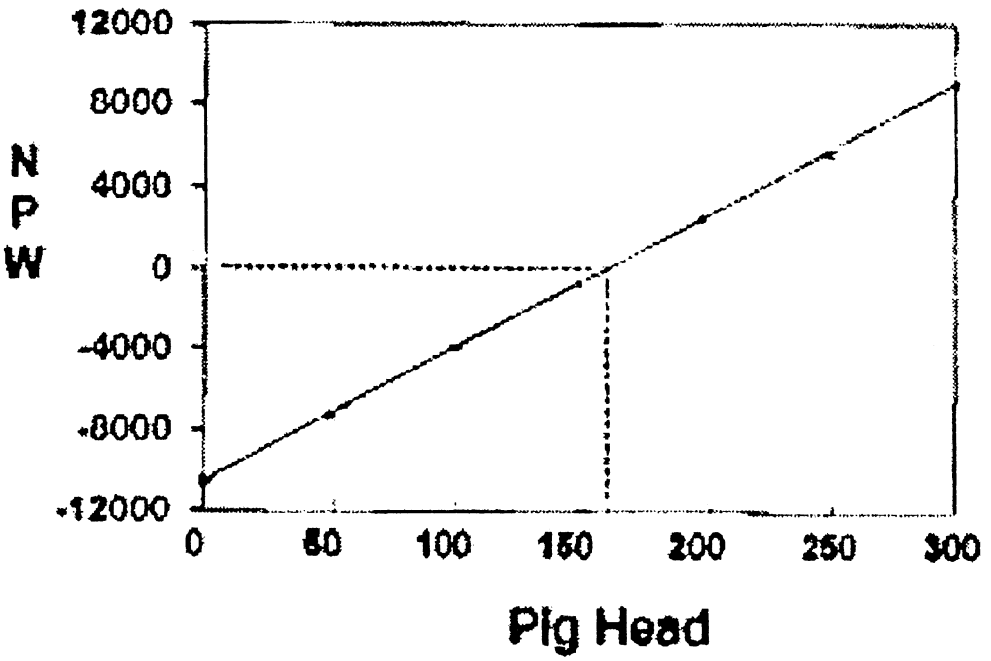

Figure 11. Determination of NPW breaken point with different sizes of operation (Yang, 2001)